PNI Sensor's Magneto-Inductive Technology

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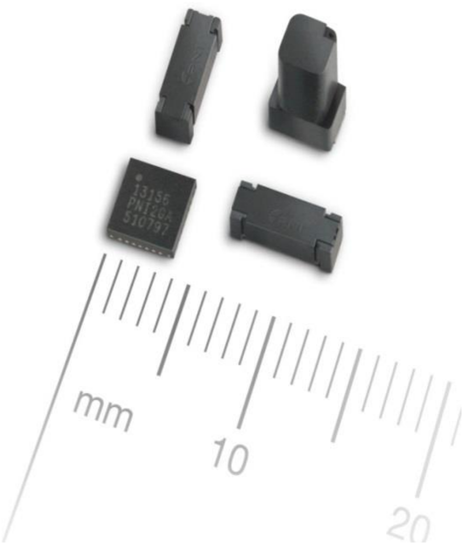
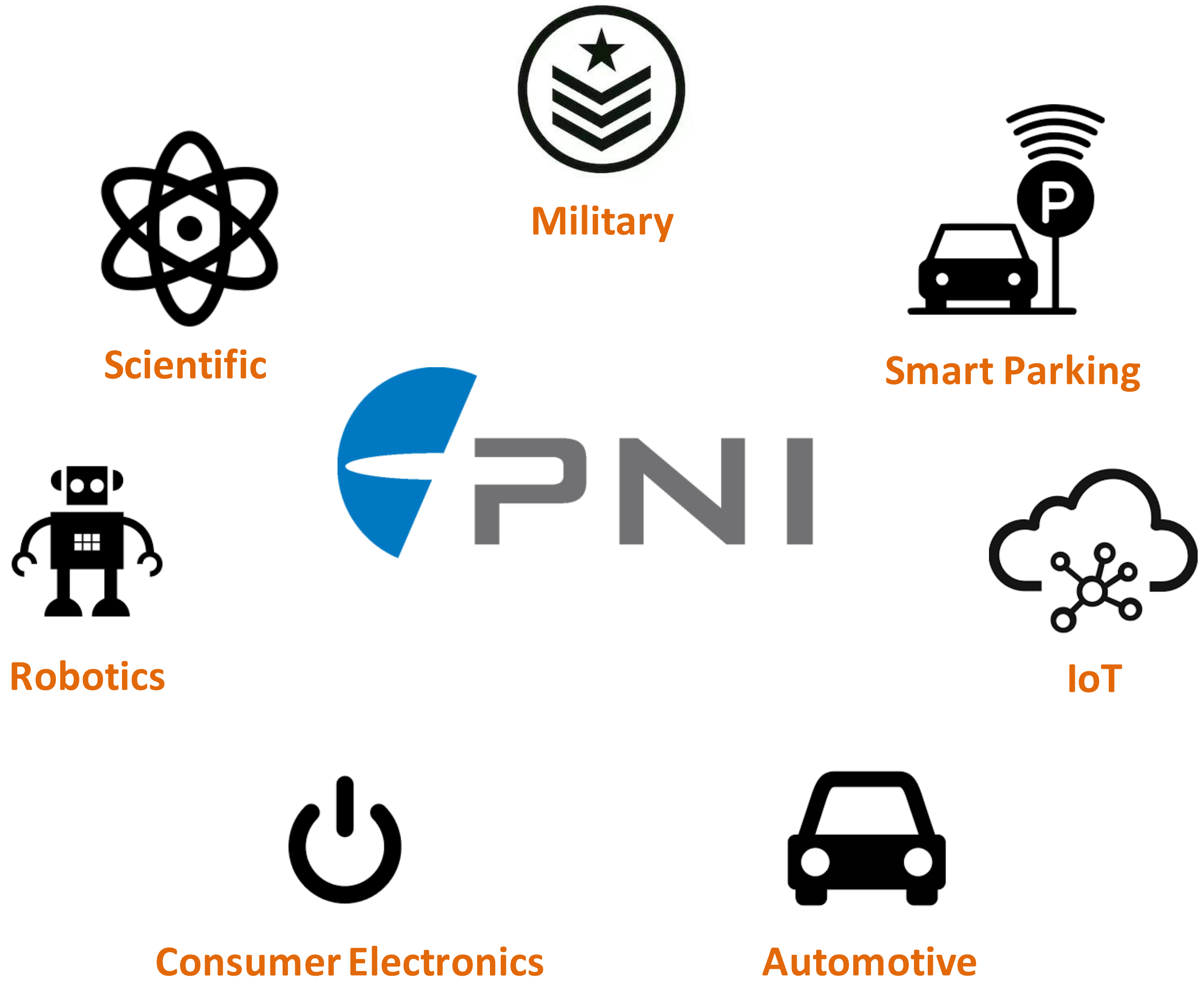
About PNI Sensor

- PNI is a positioning and navigation product and technology company that provides highly accurate, precise position and navigation data to systems using proprietary sensors, algorithms and Edge AI
- Headquartered in Santa Rosa, California
  - PNI manufactures its magnetometers in Santa Rosa
- Technology includes:
  - High-performance magnetic sensors
  - Location and motion coprocessors
  - Military-grade sensor modules
  - Edge AI and sensor fusion algorithms
  - Complete sensor systems



Applications



Customers

PNI's technology is used by leading, global organizations in applications where a high degree of accuracy, continuous reliability, and low power consumption are required.

L3HARRIS™
FLIR®
Elbit Systems™
DEPARTMENT OF THE NAVY · UNITED STATES OF AMERICA
THALES
NAVSEA
NAVAL SEA SYSTEMS COMMAND
magseis fairfield
TELEDYNE TECHNOLOGIES
ULTRA
iRobot®
CUBIC™
JENOPTIK
sparton
QIOPTIQ
Photonics for Innovation
QinetiQ
North America
Foster-Miller
SONY
GM
Ford
ST
ASUS®
Nintendo®
SAMSUNG
htc®
PNI

Products and Technologies

Magnetic Sensors

High Sensitivity
Low Noise
No Bias Drift

Commercial
<13nT noise
RM3000
RM3100

Military
<7nT noise
Midas
SENR

Custom
Formula one Torque sensor
SEN QT

DMC/AHRS/IMU Modules

Targeting Modules
Headway
TargetPoint3
TargetPoint SX
TargetPoint TCM

Digital Magnetic compasses
PrimePro
SeaTrax3

AHRS
Trax2
Headway
NaviGuider

APNT Modules

FORT
Self-contained Dismounted Soldier Tracker
Pedestrian Dead Reckoning

Algorithm/Edge AI Software

Location Algorithm
Indoor and outdoor location
Fusion of sensor location, GPS and RF beacons

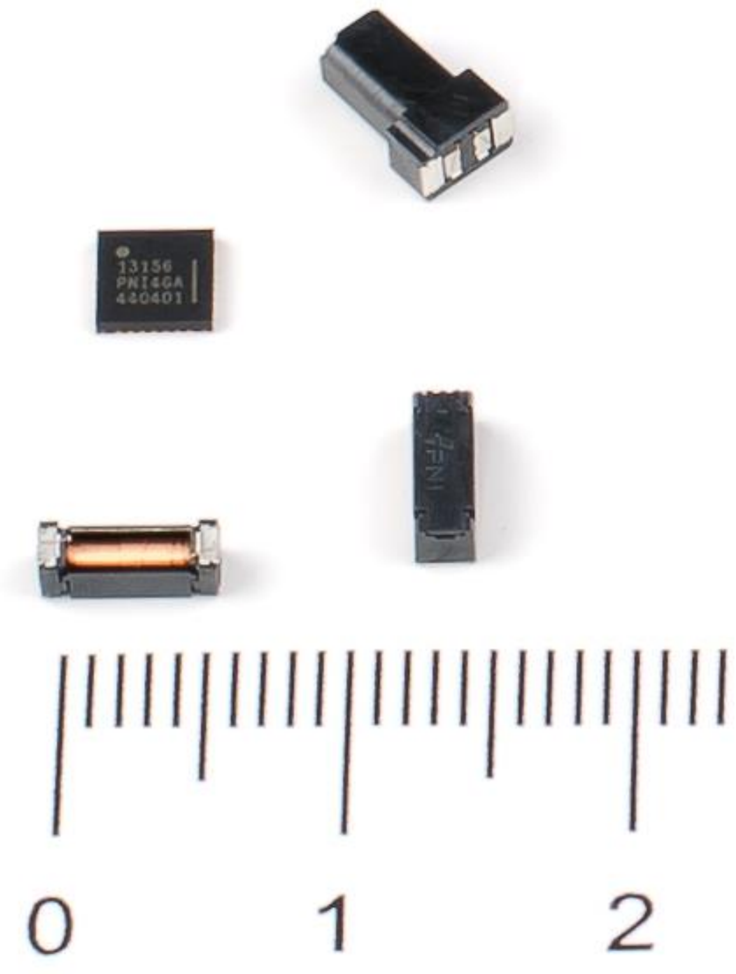
Sensor Fusion Algorithms
Configurable 15 state Kalman filter

Magnetic Interference rejection
Kalman filter
Background Autocalibration
ML Continuous Calibration

Sensor Fusion Coprocessors
Lowest power ASIC with embedded sensor fusion algorithms

Vehicle Detection
Magnetic signaturing
Edge AI

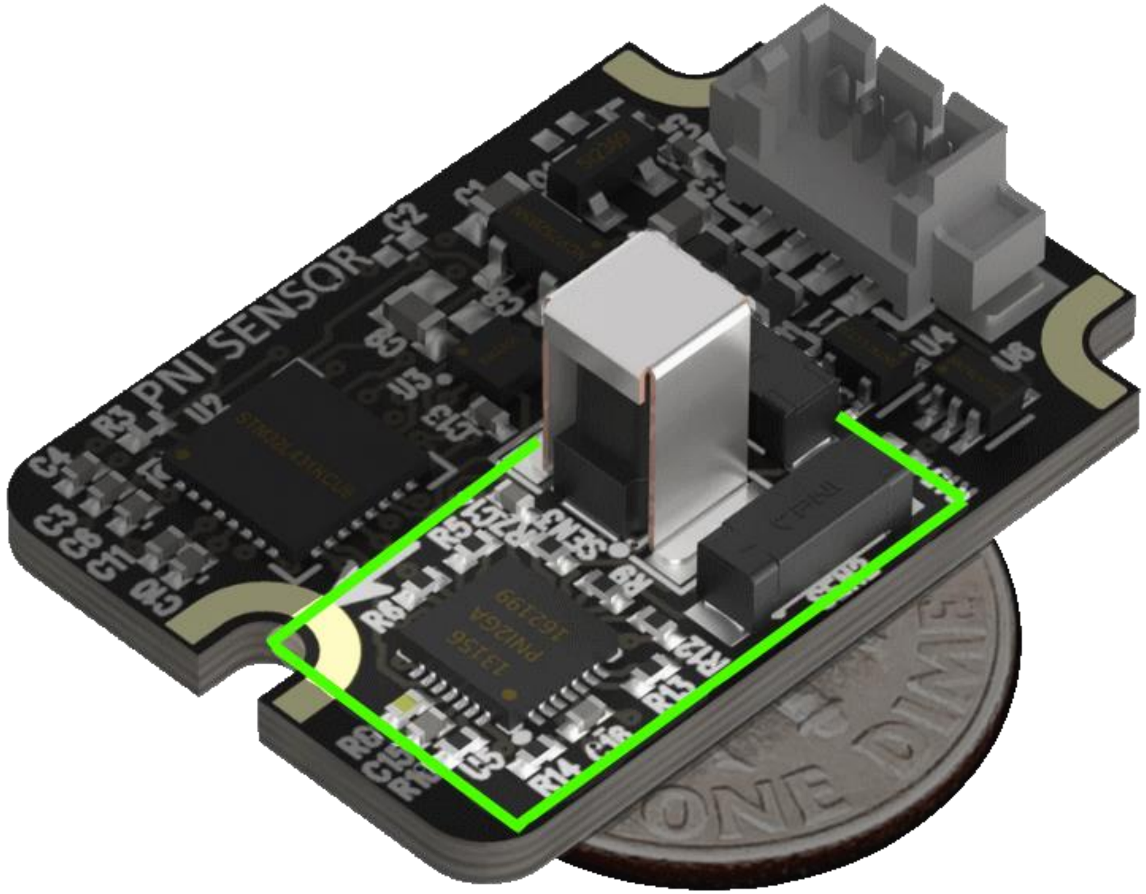
RM3100 Magnetometer Sensor



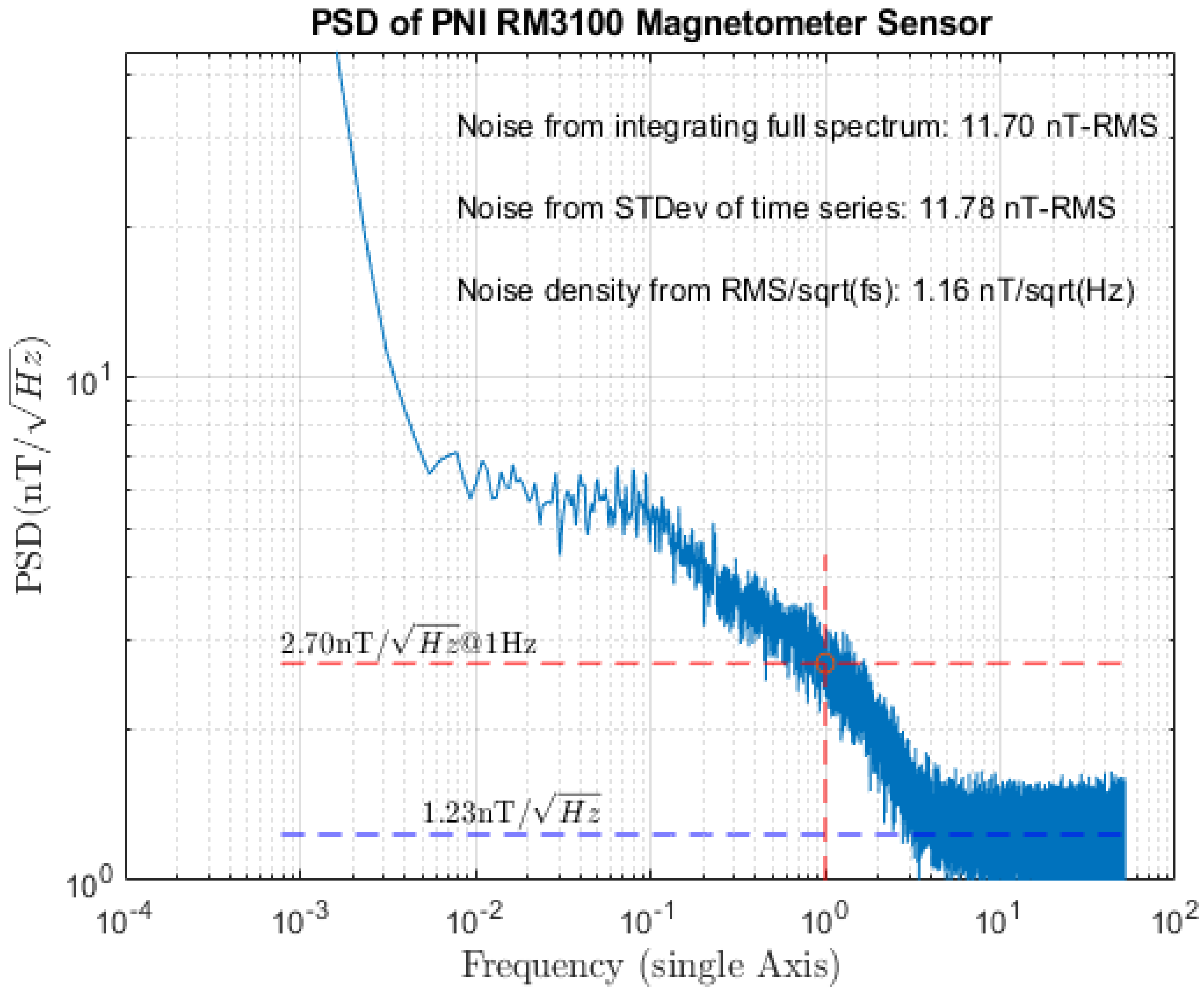
- Low Noise: $1.2nT/\sqrt{Hz}$ typical
- High linearity: 0.5% ±200uT
  - Calibrated out at PNI factory for modules
- Field Range: ±800uT
- Low current: Down to 70uA at 8Hz
- Output is inherently digital (No internal or external ADCs)
- One MagI2C measures 3 sensors for a 3-axis vector output

RM3100 System Circuitry

- Small circuit footprint: 160mm^2
- I2C or SPI digital interface
- Operating range of 2V to 3.6V



Noise Density



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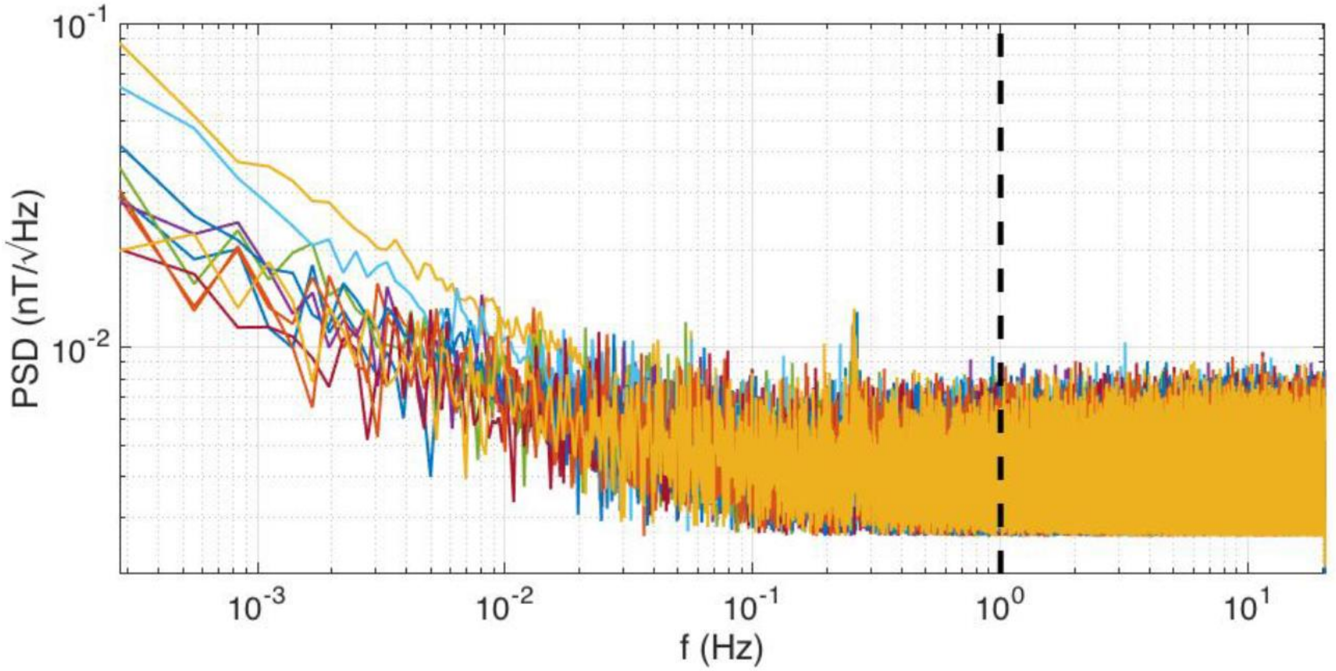
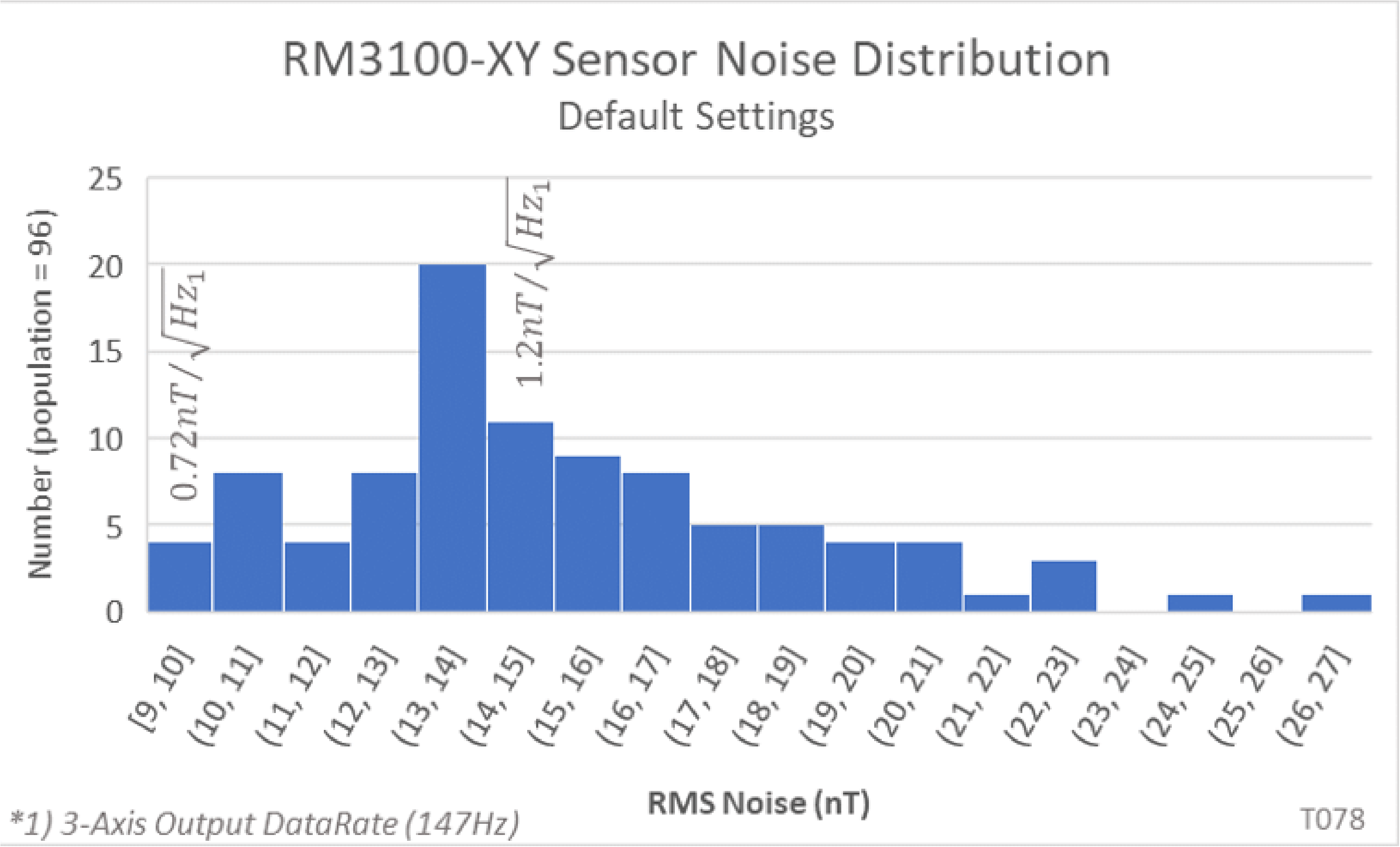
Noise Floor

- Noise floor of 4pT/rt-Hz @ 1Hz by performing a fast Fourier transform of the autocorrelation function of the measured signal[1]
- 8.7nT @ 40Hz and 2.7nT @ 1Hz



[1]Source: Regoli, L. H., Moldwin, M. B., Pellioni, M., Bronner, B., Hite, K., Sheinker, A., and Ponder, B. M.: **Investigation of a low-cost magneto-inductive magnetometer for space science applications**, Geosci. Instrum. Method. Data Syst., 7, 129–142, https://doi.org/10.5194/gi-7-129-2018, 2018.

Noise Distribution



$\bar{x}$ 14.8nT-RMS
σ 3.4nT-RMS
99% 24nT-RMS

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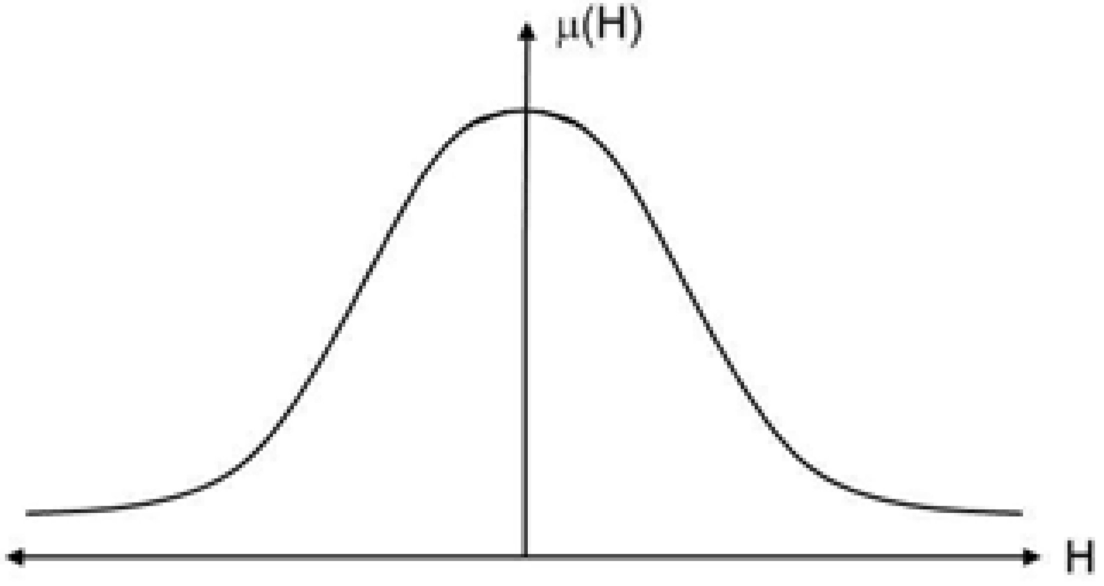
Permeability (µ) of Magnetic Material

Properties

- Permeability (µ) is the first derivative of a materials B/H curve
- As magnetic field increases µ decreases
- Inductance of an inductor with a magnetic core is proportional to µ

$$L \equiv \mu_0 + \mu_r$$

Typical μ_r curve of a core material

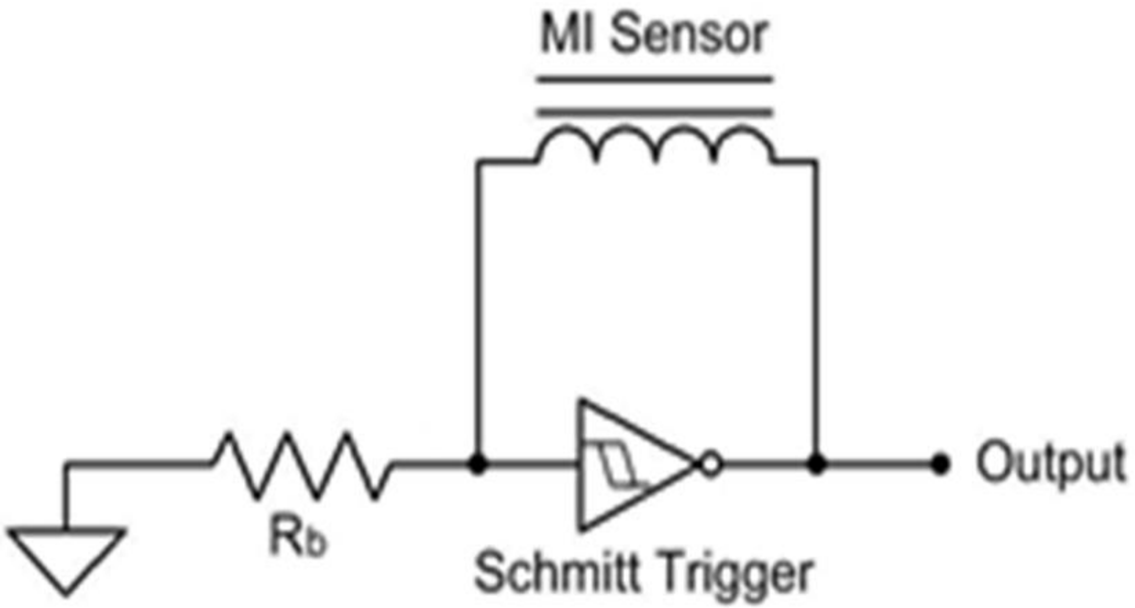


L/R Relaxation Oscillator

Attributes

- L (sensor) Has a DC bias current
- $f = k\frac{R}{L}$
- $\tau = k\frac{L}{R}$ (τ proportional to L)

Schematic

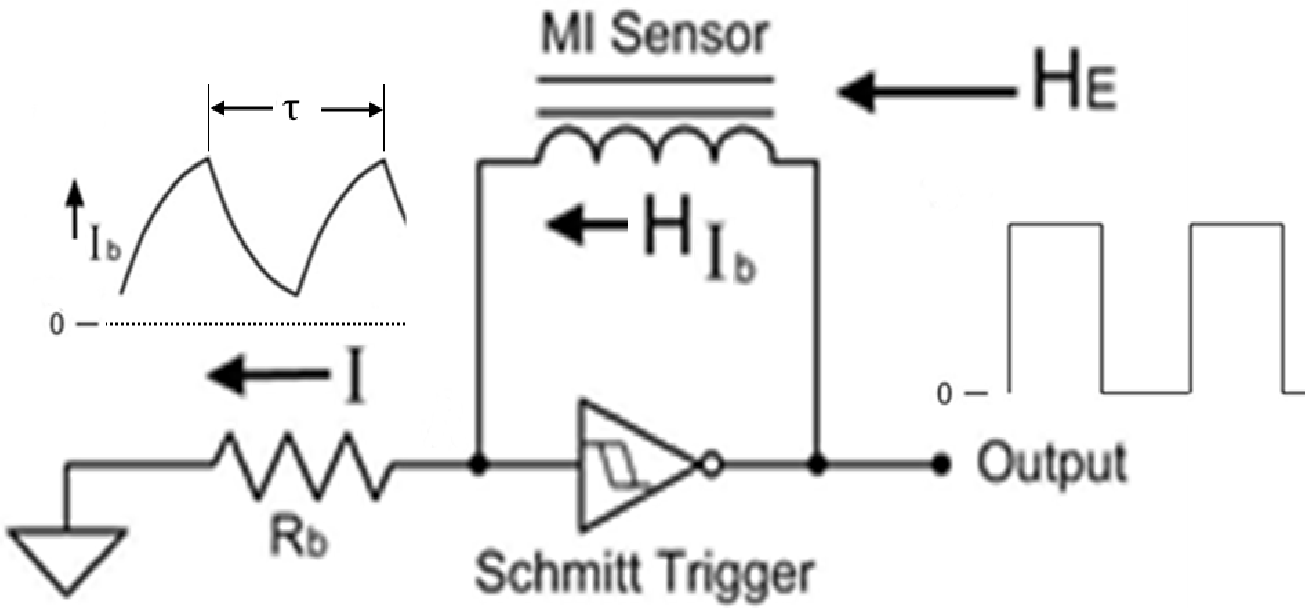


RM3100 Sensor - A field dependent Inductor

Attributes

- Saturable-core Inductor
- The DC bias of an L/R relaxation oscillator magnetizes and partially saturates the core. An external field in the sensors sensitive axis increases or reduces the amount of saturation.

Simplified Schematic

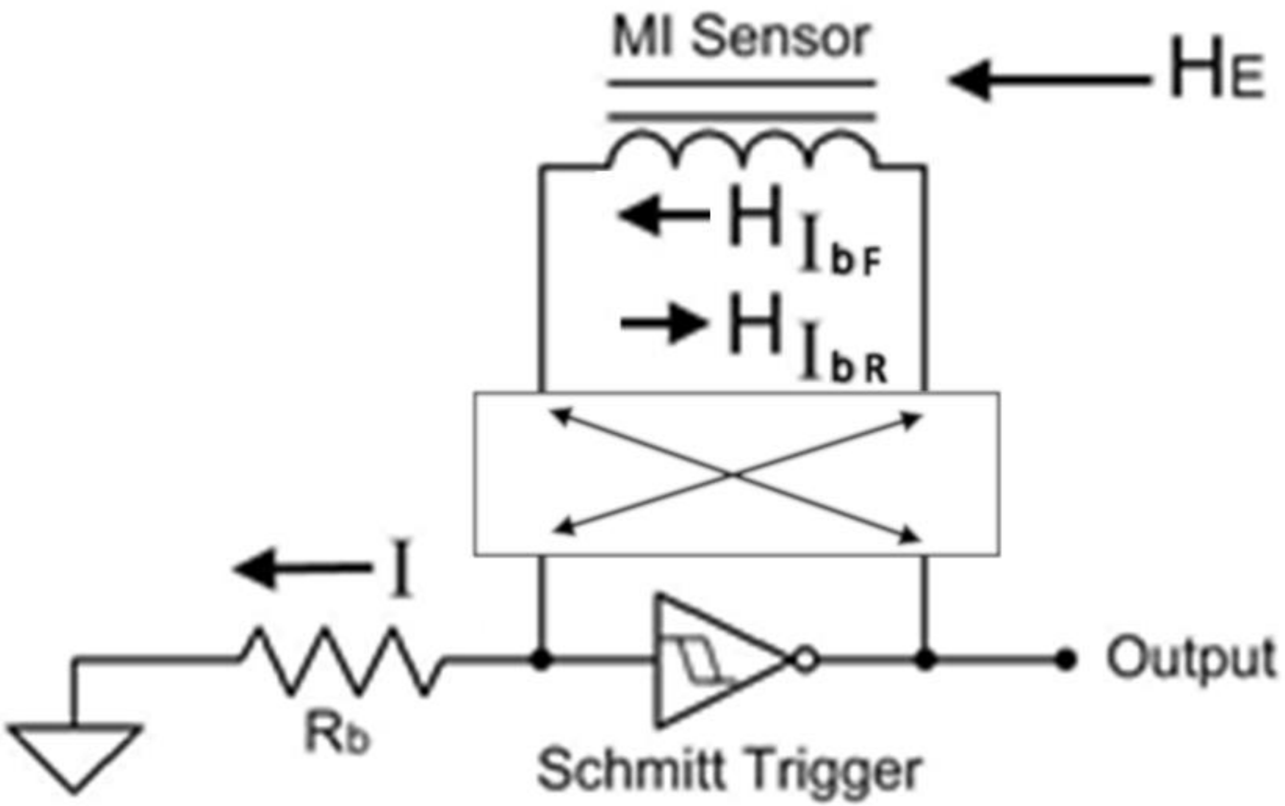


Quasi-Differential Measurement

Means

- Electronically transposes the sensors electrical direction in the circuit

- The output period of oscillation yields a τ_P and τ_N

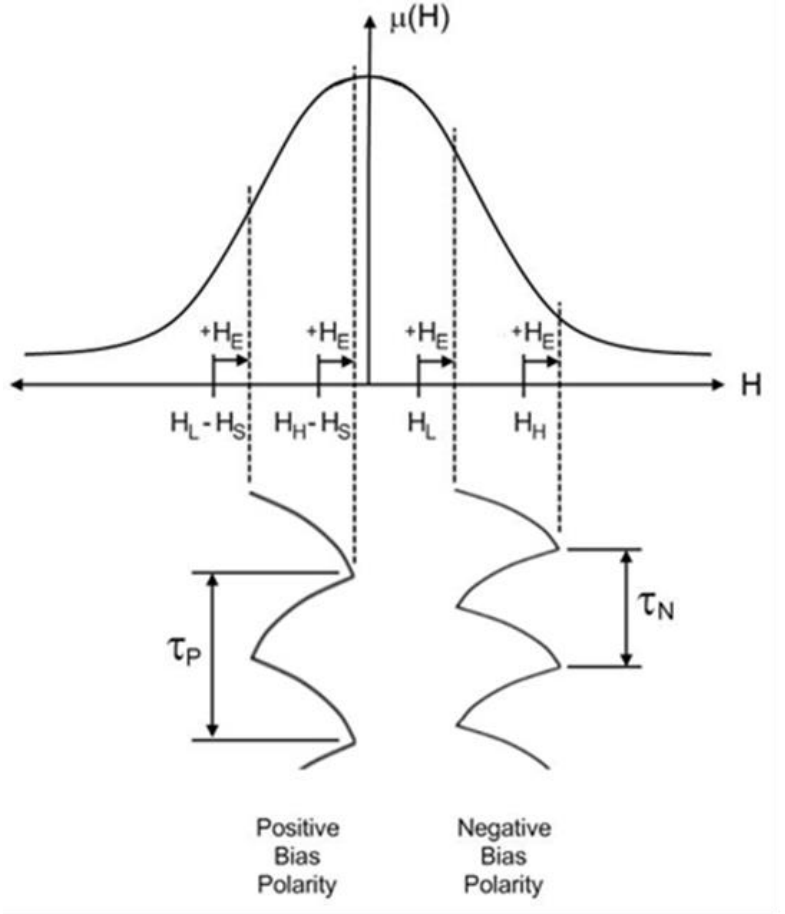


Transposed Signal Math

Analysis

- Subtracting τ $_P$ from τ $_N$
- $\tau_t = \tau_P - \tau_N$
- $\tau_t = (\tau_{H_{IP}} + \tau_{HE}) - (\tau_{H_{IN}} - \tau_{HE})$
- $Since: H_{IP} = H_{IN} \ then$
- $\tau_t = 2\tau_{HE}$

- Temperature effects on the $\tau_{H_{IP}}$ and $\tau_{H_{IN}}$ portions cancel



Practical Observations

Temp Response on a Board

- Not quite all temperature error cancels out, especially in practical applications in a larger system
- The primary causes of temperature error are clock timing and residual inductance thermal dependencies
- Most of this can be removed with linear corrections, often common coefficients depending on application
- PNI uses a non-linear correction in most of its modules for maximum performance
- Z sensor tends to be less impacted than X/Y sensors

	Correction	X	Y	z
RM3100 Gain (normalized to 50uT gain)	Raw Linear Correction PNI's Non-Linear Correction	0.05 counts/uT/K 0.006 counts/uT/K 0 counts/uT/K	0.06 counts/uT/K 0.005 counts/uT/K 0 counts/uT/K	0.02 counts/uT/K 0.003 counts/uT/K 0 counts/uT/K
RM3100 Offset	Raw Linear Correction PNI's Non-Linear Correction	0.035 uT/K 0.016 uT/K 0.002 uT/K	0.05 uT/K 0.022 uT/K 0.0025 uT/K	0.032 uT/K 0.0038 uT/K 0.0011 uT/K

Application Tip

- Oversampling
  - Lessens the effects of CMOS 1/f noise on low bandwidth measurements.
  - Keep measurement integration periods below 2.5ms, which is about 200 oscillator cycles, or Cycle Counts (CC). 1.5ms, or 125CC is ideal for very long total measurement intervals
- Run only one sensor axis per MagI2C controller IC
  - Allows longer sampling integration period. Does not have to time share with other axes.
  - All Sensor would oscillate(measure) simultaneously and thus are chronologically correlated.
  - Sensors must be separated, or they will interact.